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ORIGINAL RESEARCH

# NEUROMUSCULAR CONTROL DURING PERFORMANCE OF A DYNAMIC BALANCE TASK IN SUBJECTS WITH AND WITHOUT ANKLE INSTABILITY

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## ABSTRACT

***Design:*** Cross-sectional, controlled laboratory study

***Background:*** Lateral ankle sprains are common injuries and often lead to chronic ankle instability (CAI). Individuals who previously sustained a lateral ankle sprain, but did not develop CAI, termed copers, may have altered postural control strategies compared to individuals who have developed CAI. These altered postural control strategies may allow for more appropriate dynamic stabilization of the ankle joint after injury compared to those seen in patients who have developed CAI.

***Objective:*** To compare lower leg biomechanics, as well as electromyographic (EMG) activation of the tibilias anterior and peroneus longus muscles, during the posteromedial reach of the Star Excursion Balance Test (SEBT) in individuals with healthy ankles, copers, and those with CAI.

***Participants and Methods:*** 30 participants (12 control, 9 copers, 9 CAI) divided into three groups based on ankle sprain history and Cumberland Ankle Instability Tool score. Kinematic, kinetic, and EMG data were collected during three posteromedial reach trials on the SEBT.

***Main Outcome Measures:*** Primary outcome measures include SEBT normalized reach distance in the posteromedial direction and average integrated EMG activation of the tibialis anterior and peroneus longus muscles during the reach. Secondary outcome measures included sagittal and frontal plane ankle complex angles and moments and sagittal plane knee angles and moments. Data were analyzed between groups using a one-way ANOVA model.

***Results:*** No significant differences in reach distance or kinematic and kinetic outcomes were found between groups. The activation of the tibialis anterior and peroneus longus muscles was significantly different between groups ($p = 0.033$ and $p = 0.014$, respectively). The post-hoc analysis revealed that the coper group had significantly higher muscle activation compared to the control group, but not to the CAI group.

***Conclusion:*** CAI did not alter kinematic, kinetic, or reach performance during the SEBT. When compared to controls, copers appeared to have greater activation of the ankle musculature, which may increase stability of the ankle complex during a dynamic balance task.

***Level of Evidence:*** Prospective Cohort level II

***Keywords:*** Copers, electromyography, motion analysis, Star Excursion Balance Test

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## INTRODUCTION

The incidence of lateral ankle sprain has been estimated to be about 2.15 per 1000 person-years in at risk populations (e.g., athletes) in the United States.[1] The rate of recurrence of lateral ankle sprains may be as high as 70% in active individuals,[2] and approximately 40% of individuals with an initial lateral ankle sprain will develop longstanding ankle dysfunction (recurrent sprains, pain, and instability), also known as chronic ankle instability (CAI).[3] The long-term consequences of CAI are still unknown, however, it has been postulated that both instability and recurrent sprains may damage the articular surface of the joint, thus increasing the risk of developing osteoarthritis.[4]

Evidence exists that postural control is altered after an acute lateral ankle sprain.[5] While these postural control changes have been considered consequences of local proprioceptive deficits,[6,7] recent evidence suggests that they may result from central motor control deficiencies.[8,9] Authors have described that postural control is also impaired in the uninjured limb, suggesting that recurrent sprains may be the consequences of both centrally mediated deficits and local sensorimotor insufficiencies.[10,11] Specifically, Hass et al.[12] found that supraspinal motor control was altered in subjects with CAI to reduce the postural demand on the involved limb. This finding was supported by the work by Pietrosimone and Gribble,[13] who found that corticomotor excitability was diminished in subjects with CAI. Discrepancies exist in the literature regarding postural control in individuals with CAI.[5,14] Traditional tests used to assess postural control, such as single leg stance and center of pressure sway, have been shown to detect balance deficits in subjects following an acute lateral ankle sprain.[5,10] However, injured subjects returned to their baseline in about four weeks,[10] suggesting that these traditional tests, which are static in nature, may not be sensitive enough to detect longstanding CAI balance impairments.[5] Balance deficits have been found in subjects with CAI during more challenging tasks such as jump landing[15] and during the execution of the Star Excursion Balance Test (SEBT),[16,17] suggesting that more dynamic balance testing scenarios should be studied. Additionally, inconsistent inclusion and exclusion criteria in establishing CAI may have led to these controversial results.[5]

The SEBT consists of a grid formed by eight lines made with athletic tape extending out at 45° arcs from each other in a star pattern.[17] (Figure 1) Patients are asked to stand in the center of the grid with one leg and reach with the contralateral leg along each direction lines. The SEBT is a well-accepted clinical balance test which has been shown to be a valid and reliable test to identify dynamic balance deficits in patients with a variety of lower extremity conditions.[18,19] The SEBT has been used to compare dynamic balance performance between subjects with CAI and healthy controls.[16,17,20] Individuals with CAI reached a shorter distance in various reach directions on the SEBT when compared to uninjured individuals and when comparing the injured leg to the uninjured leg.[16,17,21] Specifically, Gribble et al[16] reported that individuals with CAI had increased reliance on the proximal joints, and they completed the SEBT reach with greater peak flexion angles at the hip and knee joints compared to healthy controls. However, the authors did not report kinetic or surface electromyographic (EMG) measures, which limited their ability to fully detail the neuromuscular control strategies utilized by these individuals.

Not all individuals who laterally sprain their ankle develop CAI. This group of individuals, usually termed copers, can return to high functional activity without symptoms of CAI.[22,23] Copers might have

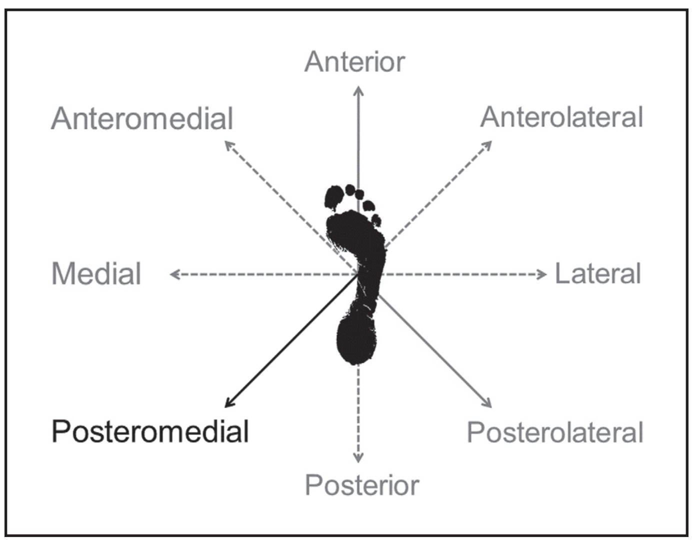


**Figure 1.** *Star Excursion Balance Test directions for a right test leg. Solid grey lines represent the reaching directions that are included also in the Y balance test. The solid black line represents the direction used in this analysis.*

acquired alternative strategies to reduce the incidence of CAI symptoms. While results of studies that have investigated mechanical variables (i.e., joint laxity, joint stiffness, and fibular position) are inconsistent,[22,24,25] subjects with CAI and copers were observed to have different balance strategies in terms of time-to-boundary during a single leg hop stabilization test and those with CAI had worse performance results.[22,23] During more dynamic tasks such as jump landing and stepping down during continuous gait, copers were found to have greater activation of the tibialis anterior (TA) and peroneus longus (PL) muscles compared to those with CAI and controls.[24,26]

EMG activation during reaching activities on the SEBT in individuals with CAI and copers has not been reported. Earl and Hertel[27] reported that during the execution of the SEBT, activation of the lower extremity muscles differed between the various reaching directions in healthy individuals. The medial and posteromedial reach directions may impose higher demand on the ankle complex as they require the highest activation of the TA muscle.[27] The posteromedial reach direction may be problematic for subjects with instability because it requires the trunk to move antero-laterally to compensate for the posteromedial reach. This movement might push the center of pressure toward the lateral edge of the foot, which can cause the foot to supinate .[24,28] The posteromedial reach is also included in the Y-Balance Test™ (www.FunctionalMovement.com, Danville, VA), which is a common balance test frequently used by rehabilitation clinicians. Therefore, to narrow the focus of the analysis, only the posteromedial reach was tested. The purpose of this study was to compare lower leg biomechanics, as well as EMG activation of TA and PL muscles, during the posteromedial reach of the SEBT in individuals with healthy ankles, copers, and those with CAI. It was hypothesized that copers would have higher activation of the ankle musculature compared to individuals with CAI and controls.

## METHODS

### Participants

Participants were recruited from both the general population and physical therapy practices. The study was approved by New York University's Institutional Review Board, and each participant gave informed consent before participating in the study. All participants met the following inclusion criteria: 1) were between 18 and 35 years of age; and 2a) had suffered at least one lateral ankle sprain (for CAI and coper groups) or 2b) had never suffered a lateral ankle sprain on either ankle (for the control group). Lateral ankle sprain was defined as an injury resulting from the ankle rolling, twisting or turning inward, which resulted in pain, swelling, and loss of function and/or participation in activity. Participants were excluded from this study if they had: 1) cardiovascular, pulmonary, neuromuscular and/or musculoskeletal diseases, disorders, or conditions that might interfere with motor performance; 2) undergone any lower limb surgeries; 3) suffered any musculoskeletal injuries within the past 6 months; or 4) consumed drugs and/or alcohol within 24 hours prior to testing that might interfere with motor performance. Additionally, participants that had poor plantar flexor muscle strength assessed via a standard single leg heel-rise-test on their test leg (subjects had to perform 25 repetitions with no limitations and minimal subjective fatigue) were also excluded to limit the possible confounding effect of muscle weakness on the SEBT performance. A customized questionnaire was used to determine: exclusion criteria; frequency and grade of previous lateral ankle sprains; whether treatment was sought after lateral ankle sprain; sport participation (hr/day); and presence of ankle pain during sport activities.

### Group Placement

Perceived ankle stability was quantified using the Cumberland Ankle Instability Tool (CAIT), which is a valid and reliable (ICC = 0.96) questionnaire used to assess perceived symptoms of instability in different functional situations.[29] A score (minimum 0, maximum 30) was then assigned based on the severity of the symptoms. Scores equal to or higher than 28 defined functionally stable ankles.[29] Scores equal to or less than 24 defined functionally unstable ankles.[29] Subjects with CAIT score between 24 and 28 were excluded from the study, although no prospective participants fell in this range.

Subjects were placed in one of three groups (CAI, coper, or control) based on history of lateral ankle sprain and perceived ankle stability as measured with the CAIT score. Subjects in both the CAI and coper groups had a history of at least one lateral ankle sprain that resulted in swelling, pain, and temporary loss of function. Subjects included in the CAI group perceived their ankle as unstable (CAIT score equal to or less than 24). Subjects included in the coper group perceived their ankle as stable (CAIT score greater than or equal to 28). Subjects in the control group had never suffered a lateral ankle sprain on either ankle and perceived their ankle as stable (CAIT score equal to or greater than 28). Kinematic, kinetic, and EMG data were collected only on the stance leg during the SEBT, which was the injured leg for the CAI and copers groups. If a subject presented with bilateral instability (CAI) or injury (copers), the test leg was the one with the lower CAIT score. If a subject had equivalent bilateral ankle status (i.e., equal CAIT scores and/or injury rates), the test leg was determined by coin flip. The test leg in the control group was always determined by coin flip.

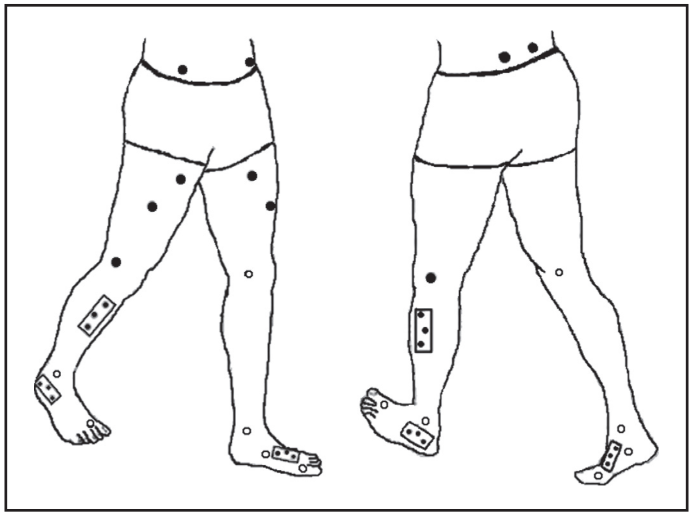

**Figure 2.** *Representative location of the markers and clusters used for motion analysis. Solid dots represent real markers; empty dots represent virtual markers digitized during the standing calibration trials; squares with three solid dots represent the clusters. During the testing, participants wore comfortable clothing that were moved/taped to accommodate the markers as needed.*

## Instrumentation

*Kinematics*

Five Qualisys ProReflex cameras (Qualisys AB Inc., Gothenburg, Sweden) tracked the 3-dimensional position in space of reflective markers at 120Hz. A custom-made marker configuration was used. Ten individual reflective markers were placed bilaterally on the following locations: anterior and posterior superior iliac spines, two individual markers on the antero-lateral aspect of the thigh, and one on the lateral condyle of the femur. Six clusters of three reflective markers were adhered bilaterally to the shank, calcaneus, and first metatarsal (Figure 2). During the standing calibration trial, markers on specific anatomical landmarks (medial femoral condyle, lateral and medial malleoli, navicular bone, base of first metatarsal, and base of third metatarsal; Figure 2) were digitized using a digitizing wand in the Visual3D software (Version 4.0, C-Motion, Inc., Germantown, MD, USA). Joint centers and six-degrees of freedom models for the pelvis, thigh, shank, and foot were built using real and digitized markers in Visual3D, which were used for the kinematic and kinetic analysis.

***Kinetics***

One force plate (Kistler Inc., Winterthur, Switzerland) was used to acquire kinetic data during the SEBT testing. Analog data were collected at 1200Hz and analyzed in combination with kinematic information using the inverse dynamics algorithms in the Visual3D software. The center of the SEBT grid was aligned with the center of the force plate.

***Electromyography***

A Bagnoli-8 EMG system (Delsys Inc., Boston, MA, USA) was used to collect the EMG signals simultaneously with the kinematic and kinetic data. The activity of the TA and PL muscles, which control ankle movement in the frontal plane, was collected. The skin at each of the placement sites was shaved, abraded, and cleaned with an alcohol pad.[30] For each muscle, one bipolar surface EMG electrode [DE 2.1 Single Differential Surface EMG Sensor, Delsys, Inc., Boston MA, USA; Sensor Contacts – 2 silver bars, 10 mm long 1 mm diameter; Contact Spacing – 10 mm; CMRR – 92 dB (typical), 84 dB (minimum)] was adhered on the belly of those muscles parallel to the direction of the muscle fibers.[30] The ground electrode was placed directly above the spinous process of $C_7$. A manual muscle test was performed to check for correct electrode placement and to check for crosstalk between muscles. An elastic wrap secured the electrodes and reduced the movement artifact. The electrodes remained affixed during all aspects of the test session. The EMG signals were acquired at a sampling rate of 1200 Hz and with a gain of 1000x [frequency response 20 ± 5–450 ± 50 Hz (80 dB/decade), System Noise (RTI) < 1.2 IV (RMS) for the specified bandwidth].

To allow for computerized measurement of the SEBT reach distance and to define SEBT reach events, a foot-switch was placed under the distal phalanx of the hallux of the reach leg and was used to track toe-off (TO - the instant the reaching foot was lifted from the ground to start the reaching task) and touchdown (TD - the instant the foot touched the ground along the specific SEBT line).

**Procedures**

Subjects were asked to stand barefoot with the navicular of their stance limb positioned over the center of the SEBT tape grid. The test was explained to each subject, as follows: they were asked to reach as far as possible along the posteromedial reach direction line with the reach leg, touch the ground lightly on the line with the most distal part of the reach foot without weight shifting, and return to the starting position while maintaining single-leg stance balance. Subjects were asked to keep the heel of the stance leg on the ground and their hands on their waist. Subjects were allowed to familiarize with the SEBT by performing three practice trials in the posteromedial reach direction.[17] After subjects were equipped with markers and EMG electrodes, three posteromedial reaches were performed and kinematic, kinetic and EMG data were simultaneously recorded. During these trials, subjects were supervised to assure the trials were performed correctly and safely, while subjects were continually encouraged to reach as far as possible. Trials were discarded and performed again if subjects did not keep their hands on their hips or their stance heel on the ground throughout the trials. Data from the three reaching trials were averaged and used for the analysis.

**Data Analysis**

Raw kinematic, kinetic, EMG, and foot-switch data were imported to the Visual3D software for visual inspection and analysis. Coordinate reference systems for each segment were created in Visual3D, which were then applied to SEBT trials. The foot-switch data were visually examined to determine TO and TD for all SEBT trials. Specifically, the frame in which the force trace dropped to 0 was considered TO, while TD was defined as the frame in which the force trace rose above 0. The position data of all reflective markers were smoothed using a low-pass, 2$^{nd}$ order, zero-lag Butterworth filter with a cutoff frequency of 7Hz. Joint rotations were calculated to describe the movement of the stance leg during the SEBT reaches. To standardize the kinematic data, joint rotation angles are presented as the difference between the angle at TD and TO. Although the pelvis segment was created, the markers on the pelvis were obstructed during the SEBT reaches on numerous occasions. Thus, hip kinematic and kinetic data were not included in the analysis. To simplify the analysis at the knee, only sagittal plane kinematics and kinetics were calculated and analyzed, since that is where the majority of the motion occurred at that joint. At the ankle, both frontal and sagittal plane kinematics and kinetics were calculated and analyzed.

Kinetic data were smoothed (low-pass, 2$^{nd}$ order, zero-lag Butterworth filter with cutoff frequency of 20Hz) for the analysis. Dorsiflexion/plantarflexion and inversion/eversion moments at the ankle joint and flexion/extension moment at the knee joint were calculated. Joint moments were normalized to body weight (kg) and reported as the value at TD. All reported joint moments were external joint moments.

The EMG signals were filtered (band-pass, 2$^{nd}$ order, zero-lag Butterworth filter with cutoff frequencies of 20-450Hz), rectified, and smoothed (low-pass, 2$^{nd}$ order, zero-lag Butterworth filter with cutoff frequency of 7Hz). The maximal muscle activation of the TA and PL muscles during all SEBT trials was used to normalize the EMG signal between subjects.[31] The integral of the EMG signal (area under the EMG curve) between TO and TD was calculated and used in the statistical analysis.

The reach distance during the SEBT was obtained by calculating the distance between the digitized markers on the navicular bone of the stance foot and the first metatarsal head on the reach foot at the instant the foot-switch was triggered by ground contact. Leg length was measured as the distance between the functional hip joint center (determined by using the validated functional joint center algorithm of Visual3D)[32] and the virtual marker on the stance leg medial malleolus. This measure may provide a more accurate estimate of the actual leg length than using manual measurement of the distance between the anterior superior iliac spine (ASIS) and medial malleolus, which can be subject to error (e.g., presence of hip and/or knee flexion/extension contracture, examiner error, etc.). To validate this measurement, the distance between the markers on the ASIS and medial malleolus was calculated, and a correlation of 0.95 between the two measures (ASIS – medial malleolus vs Hip Joint Center – medial malleolus) was found. All SEBT reach distances were expressed as a percent of the leg length.

### Statistical Analysis

A Shapiro Wilk's test revealed that all data were normally distributed. Posteromedial reach distance, EMG activation and biomechanical variables were compared between groups using an individual one-way ANOVA for each variable. Tukey HSD post hoc test and effect size (Cohen's *d*) were used to identify specific differences when significant group main effects were detected. Effect size was calculated using GPower software (version 3.1.2, University of Dusseldorf, Dusseldorf, Germany).[33] The alpha level was set to 0.05, *a-priori*.

## RESULTS

Thirty volunteers (17 male, 13 female, [mean ± SD] age = 26 ± 7 years, height = 1.71 ± 0.08 m, weight = 68.75 ± 13.09 kg) participated in the study. Based on the lateral ankle sprain history and CAIT score, 12 subjects were included in the control group and 9 subjects in both the coper and CAI groups. Demographic characteristics of the groups are reported in Table 1.

No significant between group differences were found for the SEBT reach and for kinematic and kinetic data (Table 2). However, the integral of the EMG signal of the TA and PL muscles were significantly different between groups (PL: $p$ = .014; TA: $p$ = .033, Figure 3). Compared to the control group, copers had significantly greater activation of the PL (115% increase, Tukey HSD p = .013, $d$ = 1.28) and TA (92% increase, Tukey HSD p = .031, $d$ = 1.14) muscles. Although not significant, the CAI group had 78% ($d$ = 1.06) and 61% ($d$ = 0.95) greater activation of the PL and TA muscles compared to the control group, respectively. Copers had approximately 20% greater activation of the PL ($d$ = 0.35) and TA ($d$ = 0.32) muscles compared to CAI, but these results were not significant.

**Table 1.** *Subjects demographic data, mean (SD)*

| | Controls | Copers | CAI |
|---|---|---|---|
| Total Subjects, # | 12 | 9 | 9 |
| Sex, male/female | 6/6 | 7/2 | 4/5 |
| Age, y | 26 (5) | 26 (3) | 26 (4) |
| Height, m | 1.69 (0.07) | 1.73 (0.09) | 1.70 (0.11) |
| Weight, kg | 65.99 (11.82) | 69.31 (12.74) | 76.77 (20.42) |
| Leg Length, cm | 81.32 (3.90) | 80.68 (5.78) | 81.54 (5.39) |
| Test leg LAS frequency | n/a | 2.11 (1.62) | 5.22 (3.15) |
| Doctor Visit for LAS, % | n/a | 44 | 55 |
| Grade of LAS (I,II,III) | n/a | 2 (0.63) | 2.17 (0.75) |
| Subjects Reporting Ankle Pain During Sport, % | 8% | 22% | 77% |
| Sport Participation, hours per day | 1.13 (0.48) | 1.28 (0.36) | 1.39 (0.33) |
| CAIT Score | 29 (1) | 28 (2) | 18 (5) |
| CAIT Score range | 28-30 | 28-30 | 10-24 |

Abbreviations: n/a, not applicable; LAS, lateral ankle sprain; CAIT, Cumberland ankle instability tool

**Table 2.** *Star excursion balance test (SEBT) reach, kinematic and kinetic data for the postreomedial direction. SEBT reach is reported as percentage of leg length. Kinematic data are reported as difference between angle at touchdown and toe-off. Kinetic data are reported as value at touchdown.*

| | Controls | | | | Copers | | | | CAI | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | 95% C.I. LB | 95% C.I. UB | Mean | SD | 95% C.I. LB | 95% C.I. UB | Mean | SD | 95% C.I. LB | 95% C.I. UB | *F* Value | *P* Value |
| SEBT reach, % | 79.1 | 8.7 | 73.6 | 84.6 | 84.2 | 4.4 | 80.8 | 87.6 | 82.9 | 11.4 | 74.1 | 91.6 | 0.981 | .39 |
| Ankle dorsiflexion angle, ° | 21.48 | 7.47 | 16.73 | 26.22 | 22.24 | 5.16 | 18.28 | 26.20 | 19.80 | 6.27 | 14.98 | 24.62 | 0.334 | .72 |
| Ankle eversion angle, ° | 7.36 | 4.09 | 4.76 | 9.95 | 9.78 | 4.05 | 6.68 | 12.89 | 11.25 | 6.23 | 6.46 | 16.03 | 1.758 | .19 |
| Knee flexion angle, ° | 44.72 | 15.12 | 35.12 | 54.33 | 44.55 | 2.62 | 42.54 | 46.57 | 38.62 | 10.57 | 30.50 | 46.75 | 0.892 | .42 |
| Ankle dorsiflexion moment, Nm/BW | 0.25 | 0.23 | 0.11 | 0.39 | 0.31 | 0.12 | 0.21 | 0.40 | 0.27 | 0.18 | 0.13 | 0.41 | 0.239 | .79 |
| Ankle eversion moment, Nm/BW | 0.33 | 0.09 | 0.28 | 0.39 | 0.39 | 0.14 | 0.28 | 0.50 | 0.38 | 0.12 | 0.29 | 0.47 | 0.790 | .46 |
| Knee flexion moment, Nm/BW | 1.47 | 0.29 | 1.28 | 1.65 | 1.41 | 0.28 | 1.20 | 1.62 | 1.30 | 0.30 | 1.06 | 1.53 | 0.904 | .42 |

Abbreviations: SD= standard deviation, C.I.= confidence intervals, LB= lower bound, UB= upper bound, SEBT= Star Excursion Balance Test, BW,=body weight.

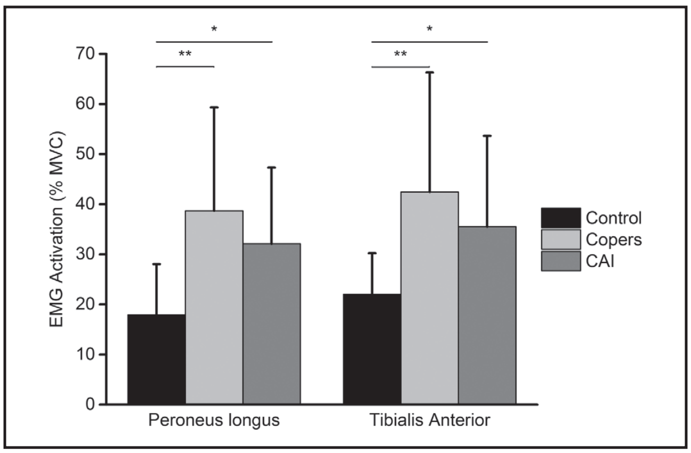


**Figure 3.** *EMG activation of the peroneus longus and tibialis anterior in the control (black bars), copers (dark grey bars), and CAI (light gray bars) groups; *, indicates significant difference between groups; **, indicates significant difference between control and coper group.*

## DISCUSSION

A modified version of the SEBT was used to investigate dynamic balance performance and ankle muscle activation patterns in three groups (CAI, coper, and control). It was hypothesized that copers would demonstrate higher activation of the tested ankle muscles than controls and those with CAI while reaching on the SEBT. The results partially support this hypothesis as copers had greater activation of the TA and PL muscles only when compared to the control group, but not when compared to the CAI group. The greater activation of the TA and PL muscles may improve the control and stability of the ankle complex during the SEBT.

During a balance task, joint stability is maintained by a complex integration of passive (articular capsule and joint ligaments) and active (muscle and proprioception) elements.[3] Following a lateral ankle sprain, the passive and active elements responsible for joint stability are often damaged.[3,33] Based on the lack of injury history and their CAIT score, controls perceived their ankle as stable, and they required less muscle activation to maintain stability during the SEBT. The coper groups showed increases in PL and TA muscle activation compared to the control group, which might represent their compensatory strategy to provide dynamic joint stability during the SEBT following injury. However, due to the retrospective design of this study, it is unknown when this change in muscular control developed. These strategies may have been present prior to the lateral ankle sprain injury, although the patterns demonstrated by the uninjured control group suggested otherwise. It is possible that copers developed this mechanism after the first lateral ankle sprain, minimizing the likelihood of suffering from the symptoms of instability and subsequent injury. On the other hand, individuals with CAI had higher activation of the TA and PL muscle compared to control, but these results were not significantly different. The lack of difference in activation may suggest that individuals with CAI may not have fully developed this coping mechanism, which would put them at higher risk of recurrent sprains and instability. Future longitudinal studies should be designed to test these hypotheses.

The higher activation of the TA muscle is particularly important due to the nature of the posteromedial SEBT task. The SEBT is a closed kinetic chain activity, and while the foot is still on the ground, the shank is moving over the foot. The closed chain eversion measured in all groups during the SEBT, relates to a lateral displacement of the shank over the foot. At the same time, the external forces acted on the lateral side of the ankle as suggested by the external eversion moment. This kinematic and kinetic pattern is potentially dangerous as it may generate a lift of the medial side of the foot off the ground, making the lateral edge of the foot a fulcrum about which an inversion sprain can occur.[24,28,34] This is especially important in the posteromedial SEBT reach, as individuals shift their trunk anterolaterally during that task in order to counteract the posteromedial reach and maintain the center of pressure within the base of support (stance foot). Therefore, increased activation of the TA muscle, may be needed to control the lateral displacement of the shank in a closed chain position.[24,28,34] Gutierrez et al.[24] found that a coper group had high activation of the TA before landing on a pneumatic platform that produced a supination perturbation. Similarly, Dundas et al.[26] found that copers had higher activation of the TA muscle when negotiating a curb during gait. In the current study, copers had higher activation of the TA throughout the reaching movement on the SEBT, which, combined with greater peroneal activation, may help copers better control and stabilize the ankle during dynamic tasks.

Another interesting, yet controversial, finding was that no reach differences between the groups were found. Previous authors[16,17,21] found that subjects with CAI reached significantly less when standing on the affected leg compared to the unaffected leg and compared to a separate group of uninjured controls. The SEBT performance involves several neuromuscular systems and consequently may be affected by a variety of factors such as muscle strength, flexibility, and activity level.[35] In the CAI group of the current study, the standard deviation and range of scores on the CAIT showed that these individuals had varying disability levels, which may explain the more variable SEBT performance relative to the coper and control groups, who presented with less variability in disability level (i.e., CAIT score) and more consistent SEBT performance. The exclusion of participants with poor plantarflexor strength and the constraints placed by the position of the foot-switch under the distal phalanx of the hallux may have also contributed to the absence of any difference in reaching performance observed in this study.

The inconsistent results regarding the presence of SEBT reach deficits in subjects with CAI may also be related to the criteria used to define CAI. All three studies[16,17,21] that found significantly lower SEBT reach distances in subjects with CAI, used the following as the definition of CAI: 1) ankle sprain and "giving-way" history, 2) no ankle sprain within 6 weeks, and 3) multiple sprains and "giving-way" within the past 12 months. On the other hand, the studies that did not find differences in SEBT reach (Sefton et al.[35] and the current study) defined CAI using a validated questionnaire, along with ankle sprain history. Sefton et al.[35] required CAI subjects to report difficulties in more than one area in the Functional Ankle Instability Index (FADI) or two areas in the FADI sport. In the current study, the CAI subjects had to score 24 or less in the CAIT. These discrepancies indicate that the CAI group may not be homogenous among these studies and highlight the need for standard criteria to define CAI, including greater consistency in patient-reported functional outcomes and quantitative tests, which may help in obtaining more consistent findings among different studies.[5,33,36]

## STUDY LIMITATIONS

The small sample size and unequal group sizes are considered limitations of this study. Rehabilitation participation following the lateral ankle sprain was not assessed, so it is unknown whether copers naturally changed their motor strategy or if the change was due to a rehabilitation program. The placement of reflective markers and EMG electrodes may have generated a movement constraint that affected the SEBT performance. This might also explain the lack of difference of reaching distance relative to the previous published studies.[16,17,21] In addition, subjects were asked to reach as far as they could, but it is unknown whether they actually reached their true maximum throughout the testing.

## CONCLUSIONS

The purpose of this study was to assess lower leg kinematic and kinetic patterns, as well as TA and PL muscle activation during the posteromedial reach of the SEBT in subjects with healthy ankles, copers, and individuals with CAI. The results of the current study indicate that perceived ankle stability status did not alter kinematics, kinetics, and reaching performance during the posteromedial reach on the SEBT. Compared to controls, copers appeared to use a strategy involving greater activation of the TA and PL muscles, which may be needed to increase control of ankle stability during the posteromedial reach of the SEBT following an ankle injury.

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